

The Effect of PBL Integrated with Renewable Energy Issues on High School Students' Scientific Literacy in Energy Sources

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Article Info	Abstract
Article history: Received: April 11, 2026 Accepted: May 3, 2026 Published: July 25, 2026 Keywords: High school physics Problem-based learning Renewable energy issues Science literacy This article is licensed under a creative commons attribution-share alike 4.0 international license © 2026 Jurnal ilmiah Pendidikan Fisika	Low scientific literacy and the absence of contextual physics learning remain persistent challenges in science education. This study aims to investigate the impact of Problem-Based Learning (PBL) integrated with renewable energy issues on high school students' scientific literacy in energy sources. A quasi-experimental pretest-posttest control group design was employed, involving 68 tenth-grade students at SMA Negeri 8 Bengkulu City selected through purposive sampling. Data were gathered using context-based essay tests aligned with the PISA 2022 framework. Results from the Mann-Whitney test ($p = 0.002 < 0.05$) confirmed that PBL incorporating renewable energy issues significantly impacted scientific literacy. The experimental group outperformed the control group with a higher average posttest score (93.06 vs. 81.97) and a moderate effect size ($r = 0.371$). These findings demonstrate that integrating real-world energy contexts into PBL effectively improves students' scientific literacy achievements. Therefore, this model is recommended as a meaningful contextual strategy, in which teachers can incorporate local issues—such as the potential of Micro-hydro Power Plants (PLTMH) to concretize renewable energy concepts.
To cite this article: Pajri, A. K., Medriati, R., & Purwanto, A. (2026). The effect of pbl integrated with renewable energy issues on high school students' scientific literacy in energy sources. <i>Berkala Ilmiah Pendidikan Fisika</i>, 14(2), 274-285.	

INTRODUCTION

Scientific literacy is a fundamental competency in the 21st century that equips students with critical thinking skills and evidence-based decision-making (Auliya & Muchlis, 2024; Putri Utami & Setyaningsih, 2022). According to the framework Programme for International Student Assessment(PISA) 2022, this competency requires three core abilities: explaining phenomena scientifically, evaluating and designing scientific investigations, and interpreting data and evidence empirically (OECD, 2023a). However, scientific literacy achievement in Indonesia still faces serious challenges. The PISA 2022 results report shows that the majority of Indonesian students are still low performers in the science domain (OECD, 2023b). One of the main contributing factors is the practice of physics learning, which is still teacher-centered (teacher-centered), thus limiting active student engagement and making physics concepts feel abstract and detached from the realities of everyday life (Ahied & Ekapti, 2020; Auliya & Muchlis, 2024; Purwanto & Uki, 2023; Viyanti et al., 2021). This passive learning pattern has been shown to hinder the development of students' problem-solving and critical reasoning skills (Tulung et al., 2023).

This condition is reinforced by the research results of Erniwati et al., (2020) in the Journal, which verified that high school pupils' scientific literacy profile is generally still

in the low category. This low ability requires innovation in learning tools that can train scientific competencies continuously. In line with this, the development of innovative learning tools has proven to be an effective solution in training students' scientific literacy ([Marcelina et al., 2023](#)). Furthermore, the use of teaching materials that integrate real-world contexts and are oriented towards higher-order thinking skills is also an important strategy in improving the quality of physics learning ([Chania et al., 2020](#)).

Based on preliminary interviews with physics teachers at SMA Negeri 8 in Bengkulu City, it was discovered that despite the Independent Curriculum's establishment, tenth-grade students still face challenges in understanding physics concepts in depth. Students tend to be unable to adapt to the demands of high school learning, which emphasizes higher-order thinking skills (HOTS). Furthermore, although laboratory facilities are available, their utilization to support the development of scientific literacy is not optimal, particularly in addressing local energy issues as a learning context. In the renewable energy topic, students showed high enthusiasm, but still struggled to connect concepts to real-world problems in their surroundings. This situation highlights the urgency of implementing a more contextual learning model to support the achievement of scientific literacy in accordance with the PISA 2022 framework.

In response to these challenges, a transformation toward student-centered, context-based learning is imperative, in keeping with the Independent Curriculum's spirit ([Indarta et al., 2022](#)). In this regard, PBL is a highly relevant approach. The development of science learning tools integrated with PBL syntax has been empirically proven to significantly improve students' problem-solving abilities ([Lestari et al., 2022](#)). The PBL approach encourages students to actively engage in learning by using real-world situations as a starting point to seek information, formulate solutions, and collaborate in teams ([Ahmad, 2024](#); [Kristianti & Safira, 2023](#); [Zeidler et al., 2019](#)). In this study, the PBL model was developed more specifically by integrating renewable energy issues as the primary context. PBL with renewable energy issues is a modification that emphasizes the use of real-life problems related to the energy crisis and the potential for alternative energy sources in the immediate surroundings as catalysts for learning.

In general, the PBL syntax integrated with renewable energy issues includes: (1) orientation on real energy-based problems such as electricity crises or energy potential (e.g., micro-hydro power plants), (2) organizing students into groups, (3) investigating concepts and data, (4) developing and presenting scientific solutions in the form of clean energy ideas or prototypes, and (5) evaluating the problem-solving process. The main difference with conventional PBL lies in the context of the problems used, which focuses on energy issues relevant to students' lives. Through direct involvement in solving problems, students not only master theoretical concepts but are also able to reflect deeply on their learning process ([Novelita & Darmansyah, 2022](#)).

The success of PBL depends heavily on the relevance of the problems presented. For optimal scientific literacy development, the problems must be contextual and closely related to current global challenges ([Hartati & Hariyono, 2020](#)). One of the most pressing and highly relevant issues to integrate into physics learning is the energy crisis and the transition to renewable energy ([Amelia & Chusni, 2024](#)). This issue is not only crucial for mitigating climate change ([Judijanto et al., 2023](#)), but also provides ample space for students to explore physics concepts—such as the law of conservation of energy, power, and conversion efficiency—in a real-world setting. Issue-based learning with renewable energy has proven effective in fostering ecological awareness while honing students' analytical skills regarding energy challenges in their environment.

Several previous studies have attempted to integrate PBL with contextual issues. [Azizah et al. \(2021\)](#) and recent research from [Khairrunisa et al. \(2025\)](#) showed that PBL based on

socio-scientific issues is effective in improving scientific literacy, but the research focused more on biology and chemistry. In the context of renewable energy, [Nasbey et al. \(2024\)](#) developed an interactive STEM-PBL-based module. However, this study focused on research and development (R&D) and did not experimentally measure its impact on scientific literacy. Meanwhile, [Pratama & Zilhakim \(2022\)](#) found a positive effect of PBL on scientific literacy, but its application did not address specific environmental issues.

Based on this study, it can be identified that there is a research gap, namely the limited quasi-experimental study that explicitly integrates the PBL model with renewable energy issues in high school physics learning and evaluates its influence on scientific literacy according to PISA 2022 metrics. This study's innovation is found in the empirical testing of the application of PBL integrated with renewable energy issues with scientific literacy measurements that are in line with the PISA 2022 analytical framework, while analyzing the magnitude of its practical impact (effect size).

Therefore, this investigation seeks to ascertain the impact and measure the magnitude of the influence of the application of the model. PBL integrated with renewable energy issues on high school students' scientific literacy on the subject of Energy Sources, when compared with the learning model of PBL, which is commonly used by teachers.

METHOD

Research Design

This study employed a quasi-experimental method with a pretest–posttest control group design. Scientific literacy was measured twice, before and after the intervention, to compare the learning outcomes between the experimental and control groups. This design was selected to accommodate the natural classroom setting, where random assignment was not feasible. The use of conventional PBL in the control group reflects authentic instructional practices, allowing the study to specifically examine the added value of integrating renewable energy issues within the PBL framework.

Population and Sample

The population of this study consisted of all tenth-grade students at SMA Negeri 8 Bengkulu City. Through purposive sampling, 68 students were selected and divided into two groups: an experimental group ($n = 34$) and a control group ($n = 34$). The experimental group was taught using problem-based learning (PBL) integrated with renewable energy issues. In contrast, the control group was taught using conventional PBL as typically implemented by the teacher, without the integration of renewable energy issues or structured socio-scientific problem scenarios.

Research Instruments

Data collection on scientific literacy achievement was carried out using a test instrument in the form of open descriptive questions (open-ended) developed based on the PISA 2022 framework ([OECD, 2023a](#)). Prior to use, the instrument was validated by physics education experts and physics subject teachers to ensure the appropriateness of the content, construction, and language. The initial instrument consisted of 14 questions with several sub-questions. Based on the instrument's trial, validity analysis using the Product Moment correlation showed that three items, namely items 2a, 3a, and 11 (along with their two subpoints), were declared invalid. Thus, of the total of 14 items tested, 10 items met the validity criteria. Of the 10 valid items, only 8 were used in collecting research data, taking into account the representativeness of the indicators and the efficiency of the instrument. The reliability test produced a Cronbach's alpha coefficient of 0.894 (very high category), indicating that the instrument has excellent internal consistency. Furthermore, analysis of

the discriminating power and difficulty level confirmed that the items were classified as fair to good, with a modest level of difficulty. The eight items that met these criteria were then used in the actual research data collection.

Data Analysis Techniques

Descriptive and inferential statistics were used in this study's data analysis. Descriptive statistics were used to present the mean and standard deviation of students' scientific literacy, whereas the study hypotheses were tested using inferential statistics. Before conducting the hypothesis test, prerequisite tests are first conducted, including a homogeneity test using Levene's Test and a normality test using the Shapiro-Wilk test. If the data are homogeneous and regularly distributed, the test is used. An independent-samples t-test is used; however, if these assumptions are not satisfied, the non-parametric Mann-Whitney U test is employed. Furthermore, the effectiveness of the learning model is measured using the effect size (r) with the formula:

$$r = \frac{Z}{\sqrt{N}} \quad (1)$$

Information: Where r represents the effect size, Z is the absolute value of the Z-score obtained from the Mann-Whitney test, and N is the total sample size. The interpretation criteria for r are presented in Table 1.

Table 1 Interpretation criteria effect size r

Mark Effect Size (r)	Interpretation
$r < 0.1$	Ignored
$0.1 \leq r < 0.3$	Small
$0.3 \leq r < 0.5$	Currently
$r \geq 0.5$	Big

(Serdar et al., 2021)

The calculation of effect size is carried out based on the Z statistical value from the Mann-Whitney test using absolute values (Peres, 2026).

Research Procedures

The stages of implementing this research include the initial preparation and observation phase, preparation and validation of instruments, determination of research samples, provision of a pretest in both classes, the application of treatment (treatment) which is different in the experimental and control classes, giving a posttest, until it ends with the data analysis stage. The procedure for implementing this research is briefly described through a flow diagram (flowchart) in Figure 1.

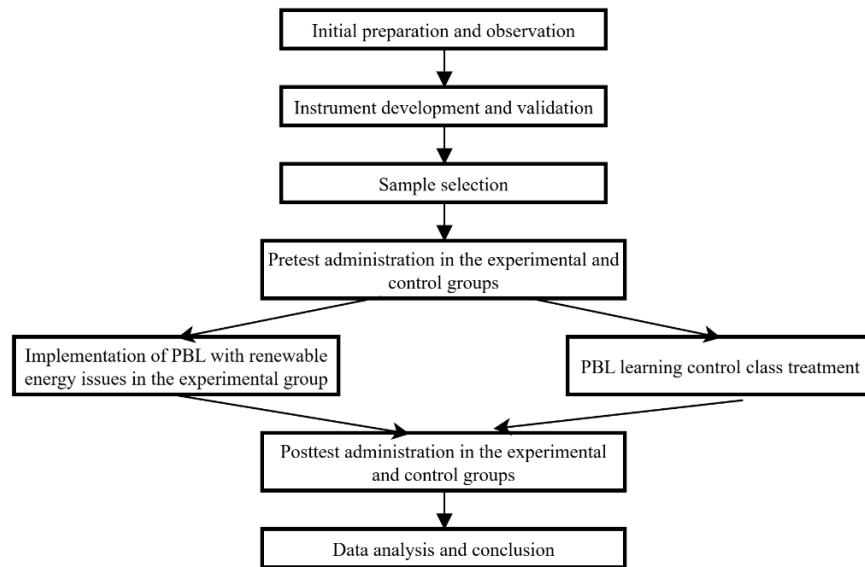


Figure 1 Research procedure

RESULTS AND DISCUSSION

Descriptive analysis was conducted to determine the initial and final scientific literacy abilities of students in both the control and experimental groups. The results of the average calculation (mean) and standard deviation (standard deviation) from the score pretest and posttest presented in Table 2.

Table 2 Average pretest posttest scores of students' scientific literacy

Class	N	Pre-test Mean	Post-test Mean	Post-test Standard Deviation	Upgrade (Points)
Experiment	34	51.65	93.06	5.359	41.41
Control	34	50.41	81.97	19.027	31.56

Based on Table 2, the average pretest scores of both groups were relatively similar, indicating comparable initial abilities. After the intervention, both groups showed improvement in scientific literacy. The control group, which was taught using conventional PBL, increased from a mean score of 50.41 to 81.97, with a gain of 31.56 points. In contrast, the experimental group, which was taught using PBL integrated with renewable energy issues, demonstrated a higher improvement, increasing from 51.65 to 93.06, with a gain of 41.41 points.

In addition, the posttest standard deviation of the experimental group (5.359) was substantially lower than that of the control group (19.027), indicating more consistent learning outcomes among students in the experimental class. These results suggest that although both instructional approaches contributed to students' improvement, the experimental treatment resulted in greater and more consistent gains in scientific literacy.

Prerequisite Analysis Test

Before conducting the hypothesis test, the posttest data were tested for normality and homogeneity. The results of the normality test are shown in Table 3.

Table 3 Results of normality test (Shapiro-Wilk)

Class	Statistics	df	Sig.	Conclusion
Post-test Experiment	0.808	34	< 0.001	Abnormal
Post-test Control	0.737	34	< 0.001	Abnormal

The results of the homogeneity test are shown in Table 4.

Table 4 Results of the homogeneity test (Levene's test)

Variables	Levene Statistic	df1	df2	Sig.	Conclusion
Science Literacy	16.355	1	66	< 0.001	Not Homogeneous

Based on Table 3, the significance value (p) for both classes is less than 0.05, indicating a non-normal distribution of the data. In addition, Table 4 shows a significance value <0.001 (p <0.05), which means the data variance is not homogeneous. Therefore, hypothesis testing is continued using non-parametric statistics. The Mann-Whitney U Test.

Hypothesis Testing and Effect Size

Hypothesis testing was carried out to ascertain the variations in the impacts of treatment on students' scientific literacy. The test results data Mann-Whitney presented in Table 5.

Table 5 Mann-Whitney U test results

Parameter Statistics	Experimental Class	Control Class
Mean Rank	41.78	27.22
Sum of Ranks	1420.50	925.50
Nilai Z	-3.061	
Asymp. Sig. (2-tailed)	0.002	

Table 5 shows that the null hypothesis (H_0) was rejected, as the Asymp. Sig. (2-tailed) value was 0.002 (p < 0.05). The experimental group obtained a higher mean rank (41.78) than the control group (27.22), indicating better overall performance. These results suggest that integrating renewable energy issues within the PBL framework provides significant added value compared to conventional PBL implementation.

Next, to measure the practical significance of the treatment, the effect size (r) was calculated as follows:

$$r = \frac{Z}{\sqrt{N}} = r = \frac{3.061}{\sqrt{68}} = r = \frac{3.061}{8.246} = r = 0.37 \quad (2)$$

The calculation results show an r value of 0.371. Referring to the interpretation criteria (Serdar et al., 2021), this value falls into the moderate category. This indicates that the implementation of the PBL model addressing renewable energy issues has significant effectiveness in improving high school students' scientific literacy.

This study shows that the application of problem-based learning (PBL) integrated with renewable energy issues significantly improves students' scientific literacy in physics. This finding supports the hypothesis that integrating PBL syntax with real-life environmental contexts can optimize students' scientific literacy achievement, as reported in previous studies (Mulia et al., 2024; F. Lestari et al., 2025). The effect size of r = 0.371 indicates a moderate level of influence, suggesting that the impact is not only statistically significant but also practically meaningful in learning. This finding highlights that the observed improvement is not merely attributable to the use of PBL itself, but rather to the integration of contextual renewable energy issues within the PBL framework. Although the control group also showed improvement, the gains were lower compared to the experimental

group, indicating that conventional PBL alone may not optimally support the development of scientific literacy without the integration of contextual issues.

This moderate effect size ($r = 0.371$) obtained in this study can be attributed to several interrelated factors. First, scientific literacy is a multidimensional competency encompassing conceptual understanding, scientific reasoning, and higher-order thinking skills (HOTS), all of which require sustained and gradual development rather than rapid acquisition within a single intervention. Second, the relatively short duration of the treatment likely limited students' full adaptation to PBL-based inquiry processes, as the shift from passive to active scientific thinking requires continuous cognitive scaffolding. Third, individual differences in cognitive style were not controlled in this study; prior research indicates that the effectiveness of PBL in enhancing scientific literacy is strongly influenced by the alignment between instructional approaches and students' cognitive styles ([Astawan et al., 2025](#)). These factors collectively explain why the observed effect remained in the moderate range. Nevertheless, the PBL model demonstrated its core strength by engaging students in authentic problem-solving, enabling them to construct conceptual understanding through inquiry rather than passive memorization. This finding is consistent with Melinda et al. (2024), who reported that PBL enhances students' motivation and learning outcomes through active involvement in exploring real-world phenomena, such as energy-related issues in their environment.

More specifically, the effectiveness profile of this model can be analyzed through the percentage of achievement of the experimental class' scientific literacy indicators, based on the PISA 2022 framework ([OECD, 2023a](#)). The proportion of students' scientific literacy achievement across the three competencies is visualized in Figure 2.

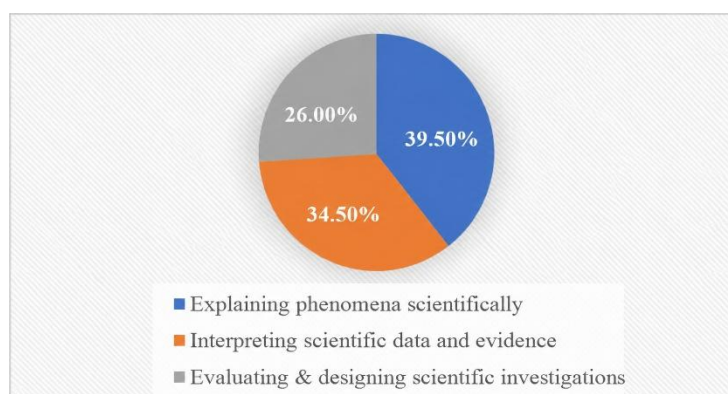


Figure 2 Percentage of achievement of scientific literacy indicators in the experimental class

Based on the visualization in Figure 2, the highest achievement is dominated by the competence of explaining phenomena scientifically with a contribution percentage of 39.5% (average posttest 8.37). The success of the PBL model is very visible in this indicator, where the experimental class recorded a difference in improvement of 4.62, far surpassing the control class which only increased by 2.76. This drastic improvement was driven by the students' ability to remember and apply physics principles (such as the law of conservation of energy) to justify their predictions regarding the potential of water energy in the surrounding area. This was strengthened by the integration of real contexts and higher-order thinking skills (HOTS) on energy material, which has been proven to strengthen students' conceptual understanding and scientific literacy simultaneously ([Chania et al., 2020](#)). The second high achievement is seen in the competence of evaluating

facts and scientific evidence, which takes up a portion of 34.5% (average 7.30). The PBL syntax that requires group investigation has been proven to be successful in training students in analyzing empirical data and evaluating energy sustainability arguments from various literature. This is in line with the PISA 2022 framework, which highlights the significance of the contextual and scientific processes ([OECD, 2023a](#)). This finding is also consistent with research by [Nasbey et al. \(2024\)](#), which states that the integration of renewable energy issues in PBL can strengthen students' analytical argumentation skills. In addition, the development of structured and innovative learning tools is crucial to stimulate students' scientific competencies in a sustainable manner ([Marcelina et al., 2023](#)).

On the other hand, the smallest portion in the diagram is shown by the ability to assess and plan scientific research, which only reached 26.0% (average posttest 5.50). Although the experimental class still showed an increase of 2.25, which was better than the control class at 1.54, this figure remained the lowest among the other indicators. Most students still experienced technical difficulties in identifying questions worthy of empirical investigation and difficulties when tasked with proposing ways to explore design procedures and experiments independently. This competency requires very complex higher-order thinking skills. This finding confirms Vygotsky's social constructivist view that Problem-Based Learning (PBL) requires social interaction processes and scaffolding instructional guidance ([Azizah et al., 2021](#); [Viyanti et al., 2021](#)). Therefore, complete mastery of these inquiry design indicators likely requires intervention time much longer than the duration of this study.

The integration of local renewable energy issues in this study further contributes to the effectiveness of the PBL model. Contextualizing the problem allows students to understand the concept of energy efficiency more concretely. This finding complements previous research showing that PBL's efficacy is greatly impacted by the relevance of the problem context ([Pratama & Zilhakim, 2022](#); [Kurniati & Adelia, 2023](#)).

Theoretically, the results of this study corroborate the assumption that scientific literacy is built not only through mastery of conceptual content but also through students' active engagement in responding to relevant socio-scientific issues. Therefore, physics learning in the 21st century requires the integration of conceptual, contextual, and scientific process dimensions in a balanced manner.

CONCLUSION

This study demonstrates that PBL integrated with renewable energy issues significantly improves high school students' scientific literacy, with a moderate effect size ($r = 0.371$). The most notable improvements were observed in the competencies of explaining scientific phenomena and interpreting scientific data and evidence. These findings indicate that integrating socio-scientific issues, such as energy-related problems, effectively supports students in contextualizing abstract physics concepts and strengthening the application dimension of scientific literacy. However, students' ability to evaluate and design scientific investigations remains relatively limited, suggesting the need for longer and more sustained learning interventions. Therefore, future research is recommended to examine the effectiveness of this approach across different physics topics and extended implementation periods to further enhance students' higher-order thinking skills.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, AKP and RM; methodology, AKP and RM; formal analysis, AKP; investigation (data collection), AKP; resources, AKP and AP; writing—original draft, AKP; writing—review and editing, RM and AP; supervision, RM and AP. All authors have read and approved the final version of the published manuscript. Authorship is limited to those who have made substantial contributions to the reported work.

AI DISCLOSURE STATEMENT

The author uses ChatGPT and Gemini during the preparation of this work for grammar refinement, manuscript editing, and sentence structure improvement. After using the tool/service, the author thoroughly accepts full responsibility for the content of this publication and evaluates and adjusts it as necessary.

ACKNOWLEDGMENTS

The authors express their gratitude to the University of Bengkulu's Faculty of Teacher Training and Education's Physics Education Study Program. for their support in this research. They also thank the principal, physics teachers, and students of SMA Negeri 8 Kota Bengkulu for their participation and assistance, as well as everyone who helped to finish this study.

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